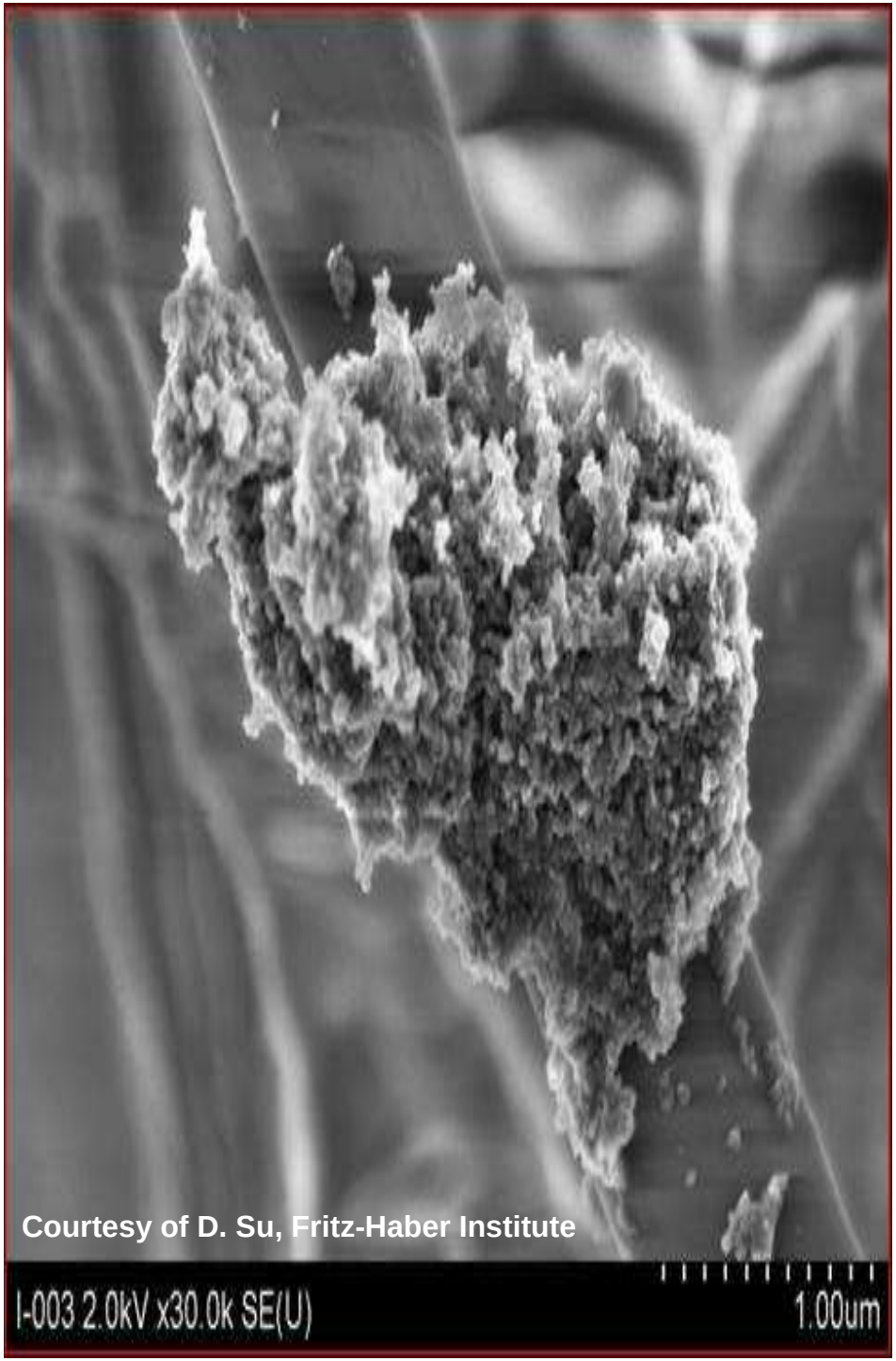


27th AAAR Annual Conference
Oct 20-24, 2008, Orlando, Florida, USA

# Ionic and Organic Species in PM Emissions from Advanced Technology Heavy-Duty Diesel Vehicles

**Alberto Ayala, Shaohua Hu, Jorn Herner, M.-C. Oliver Chang, William Robertson, John Collins, Tao Huai, and Paul Rieger**

**California Air Resources Board**

**October 23, 2008**

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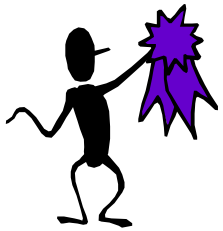
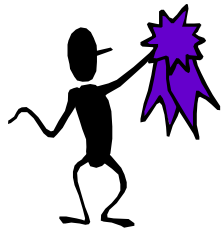


# Acknowledgements:




CO-Investigators: CARB's Monitoring and Laboratory Division, CARB's Mobile Source Control Division, University of Southern California, UC Davis, U of Wisc.

Co-Sponsors:

California Energy Commission

SOUTH COAST AQMD

In Kind Contributors:

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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D.A.R.T. Downey Area Recycling & Transfer

ELK GROVE Unified School District

SAN JOAQUIN RTD

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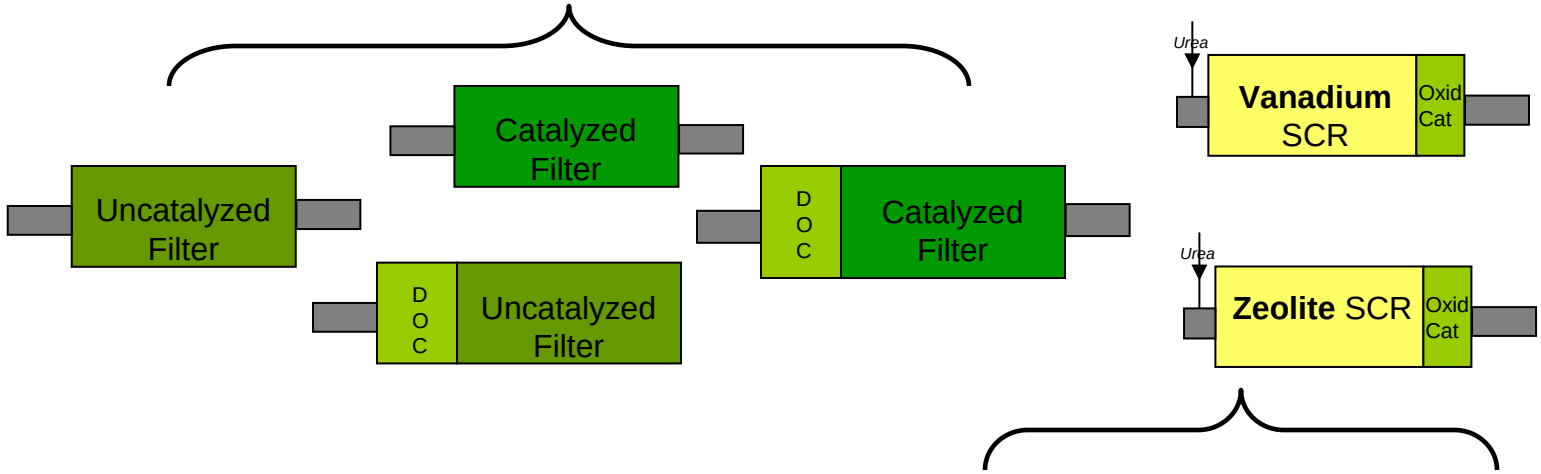
# $NO_X$ and PM Retrofits Investigated[1]

**Heavy-Duty Vehicles** + **Diesel Particle Filter** + **$NO_X$ Catalyst**




**Baseline vehicle = no retrofit**

- **One vehicle tested with DPF + SCR**
- **DPF + SCR is of special interest as it represents most advanced technology for meeting 2010 standards**
- **SCRT® systems used in this project are development prototypes not commercial units**

1. Herner et al. 2007. Towards 2010 NOx and PM emission Levels: Overview of CARB's Investigation of Advanced Heavy-duty On-road Vehicle Retrofits and Other Technologies. 26th AAAR Annual Conference, September 24-28, 2007, Reno, NV

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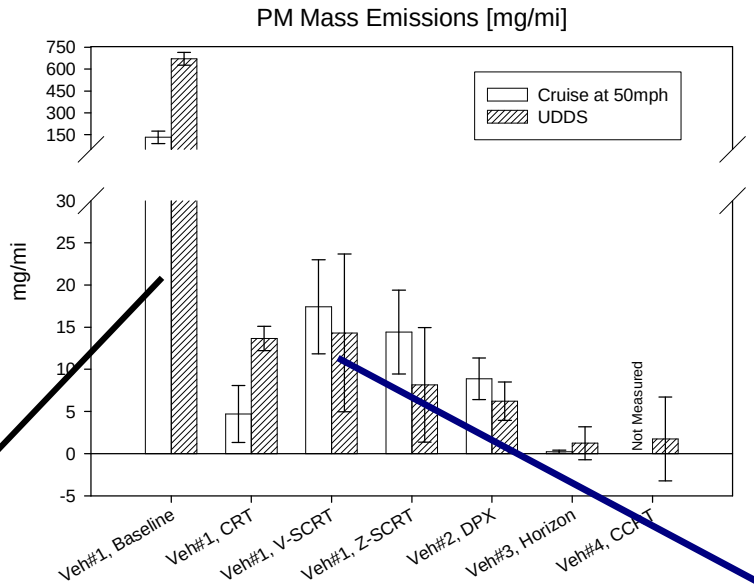
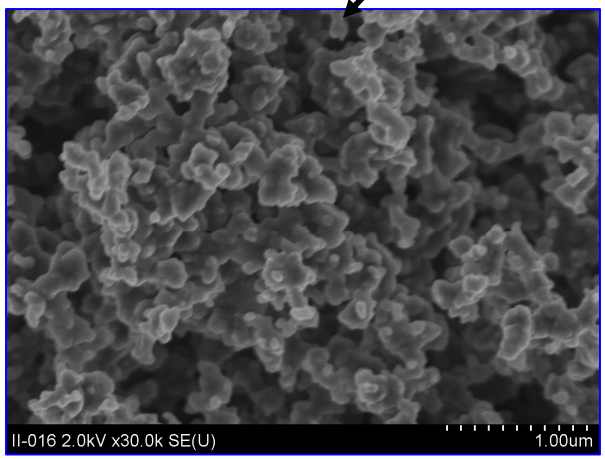
# Particle filter is game-changing technology. It achieves significant PM emission reductions from diesel engines




**PM retrofits yield greater than 90% reduction in PM emissions**

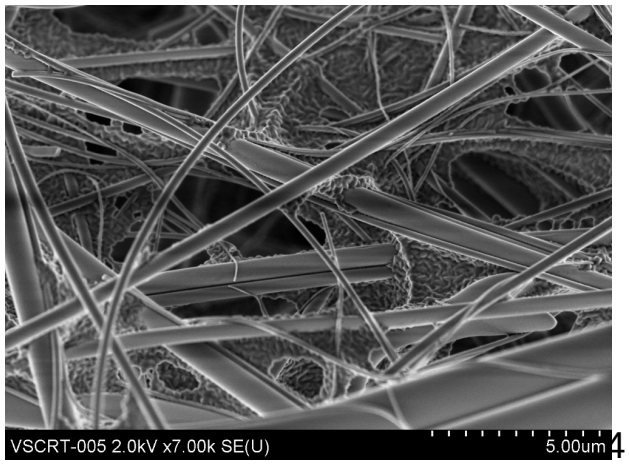
**Baseline Diesel Sample**

Agglomerates




**DPF+SCR Sample**

Clean as Blank




SEM images courtesy of D. Su, Fritz-Haber Institute

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# Experimental Setup @ CARB's Emissions Lab

Dilution Air → **CVS Tunnel** Q=2600 or 1600 cfm

Exhaust from Testing Vehicles

**FTIR**
$N_2O$, $NH_3$

**Bags**
*Gases*, ***VOCs***

**Sioutas Impactor@**
$V_2O_5$

**Filters**
**(+ vapor traps)**
***PM***, **PAHS,** Nitro-PAHs, ***Ions,*** Trace elements, ***EC/OC,*** Mutagenicity

**NanoMOUDI**
***PM***, organics and Ions

**HiVol Sampler**
Organics, Ions, Redox activity

**Thermaldenuded Sample**
Metals, Ions, Redox activity, CPC

**Cartridges**
Carbonyls

**Particle Characterization**
EEPS, DMS, multiple CPCs, PAS, EAD

| Sample Types | Filter Media | Flow Rate Range (lpm) | Method | Instrument |
|---|---|---|---|---|
| organic and elemental carbon | Quartz fiber | 38-40 | IMPROVE_A, | DRI Model 2001 |
| Ionic species | PTFE filter | 40-45 | IC | Dionex |
| PAH | TX60 | 75-80 | GC-MS | ASE-GC/MS |

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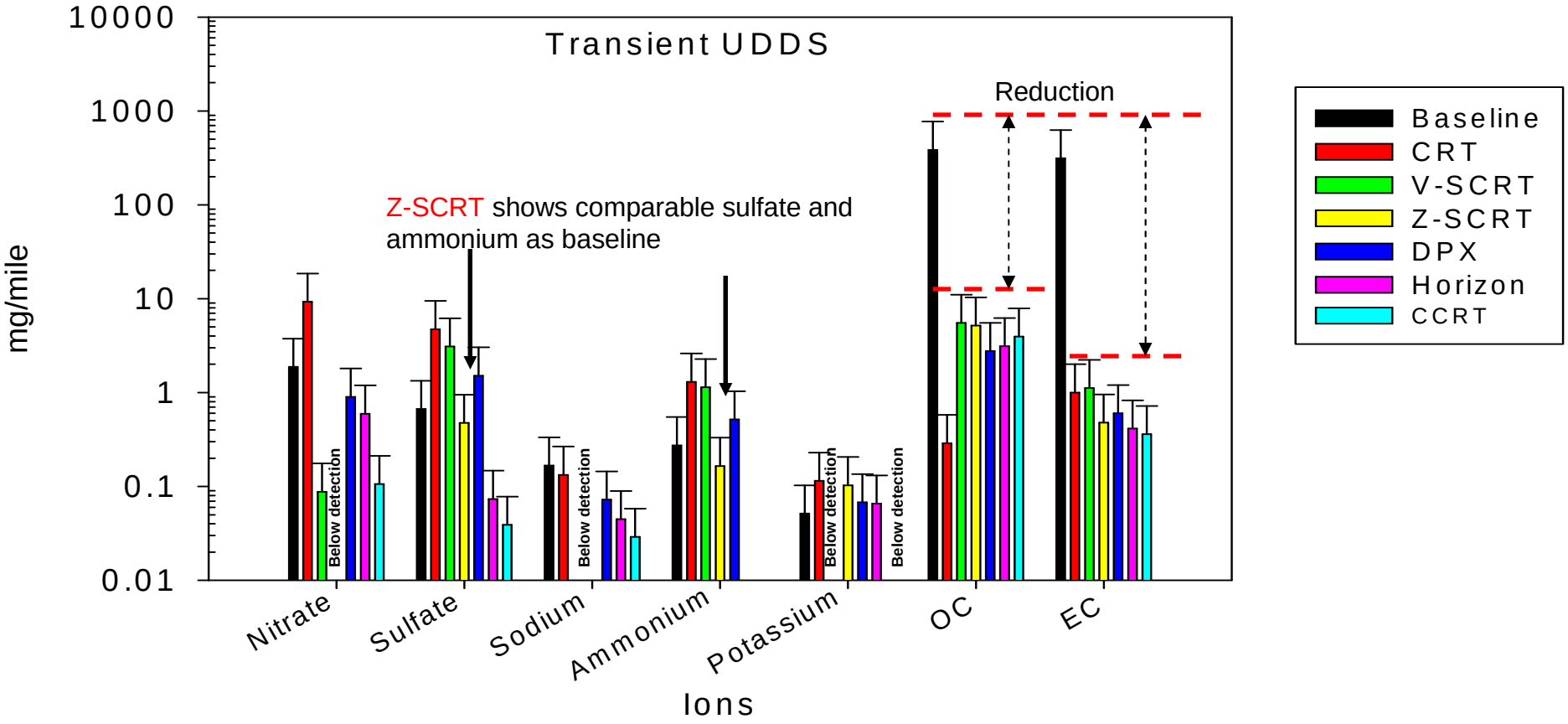
# Ions and Carbon Emissions




- **EC (i.e., diesel soot) is not dominant emission. More OC than EC**
- **All retrofits yield significant reductions of EC and OC**
- **Elevated sulfate and ammonium are observed for retrofits that also exhibit high particle nucleation**

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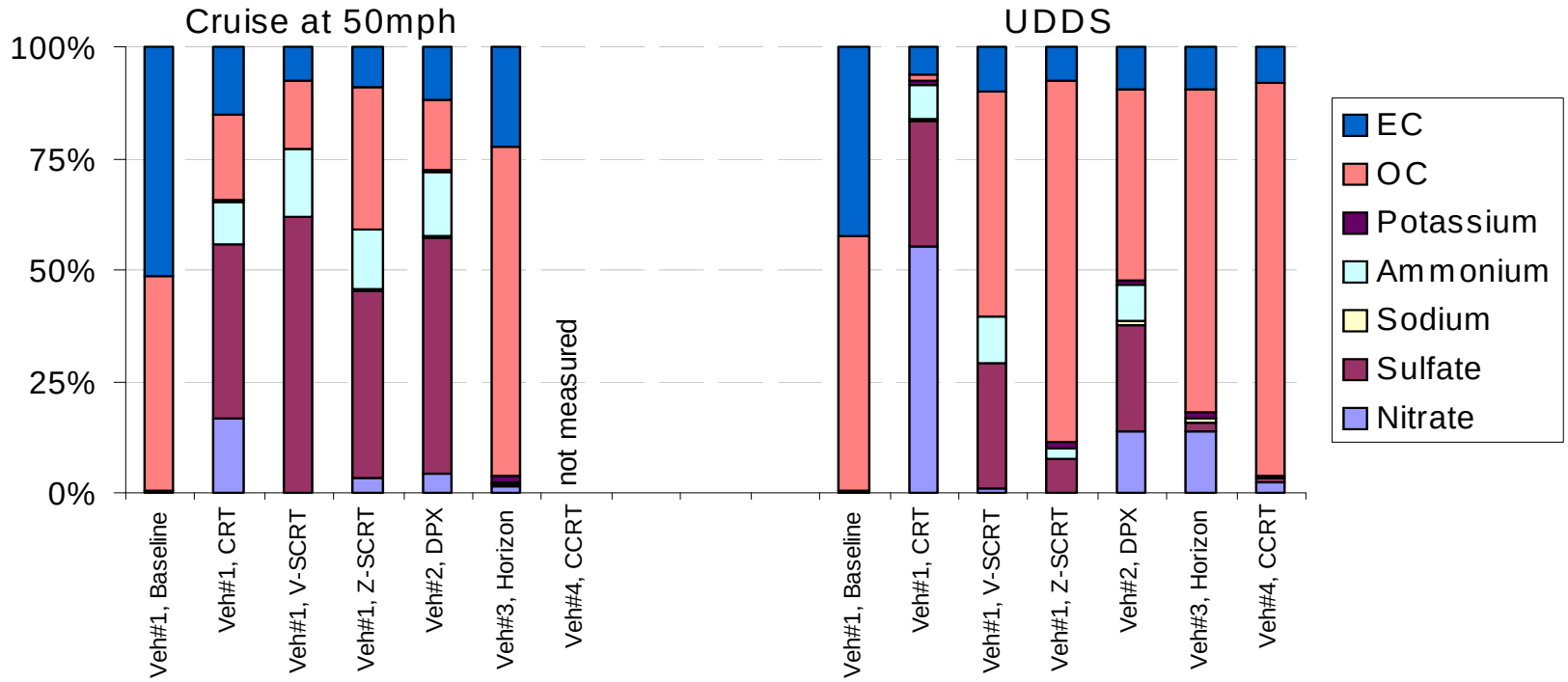
# Relative Fraction of Ions and Carbon Emissions




- **EC/OC about equal fractions of PM emissions for baseline vehicle**
- **Sulfate is dominant for most retrofits during cruise operation. 40-50% of PM is sulfate for retrofits with significant nucleation events (e.g. CRT, SCRTs and DPX)**
- **OC dominates PM emissions from most retrofits when vehicle operates over transient cycle**

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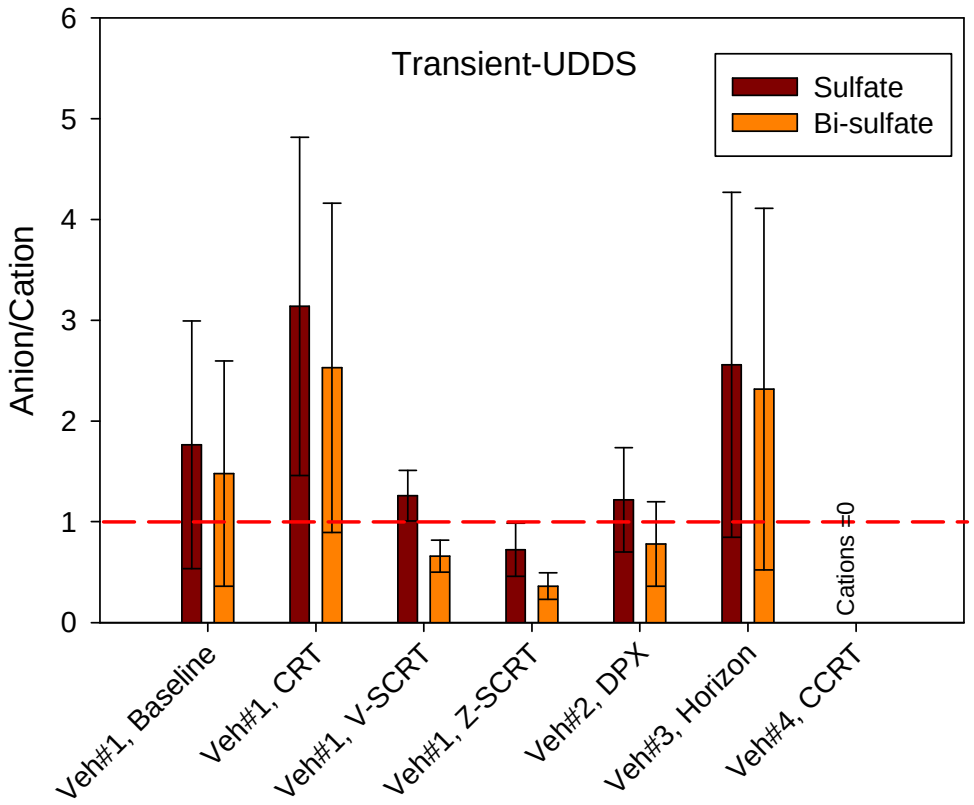
# Charging Balance (Anions/Cations)




- **Particles from some retrofits (e.g., CRT & Horizon) are more acidic (anions/cations > 1)**
- **Suspect formation of nitric acid and sulfuric acid**
- **Transient cycle increases acidity**
- **Emissions from baseline and other retrofits appear to be neutralized**

a. Anions: sulfate and nitrate
b. Cations: ammonium, potassium and sodium

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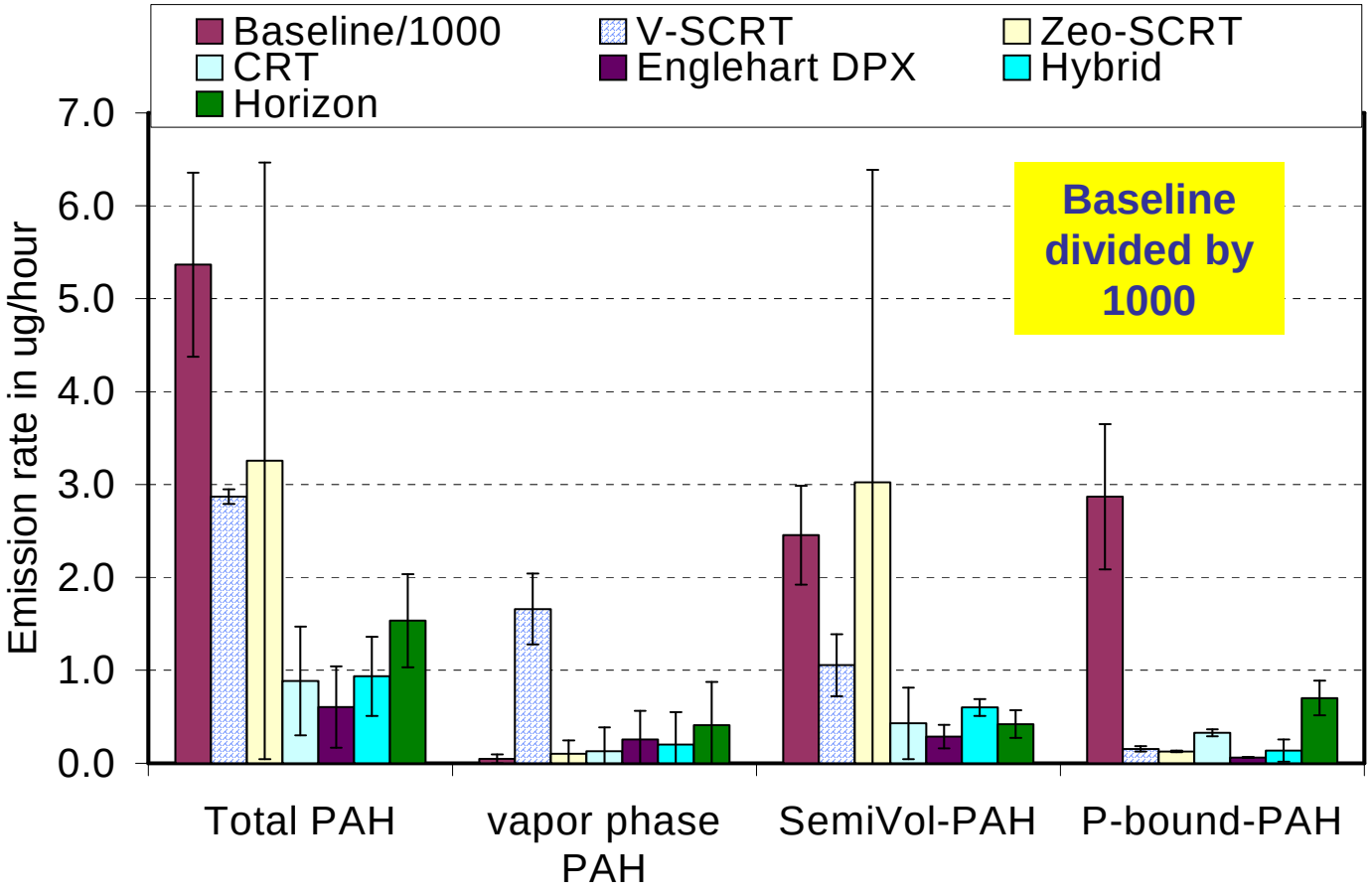
# Preliminary Results - Particle Phase PAHs[2]

UDDS






2. Chang et al. 2008. Air Toxic Emissions from HD Diesel Vehicles Equipped with NOx and PM Retrofits. 18th CRC On-Road Emissions Workshop, March 31 - April 2, 2008, San Diego, CA

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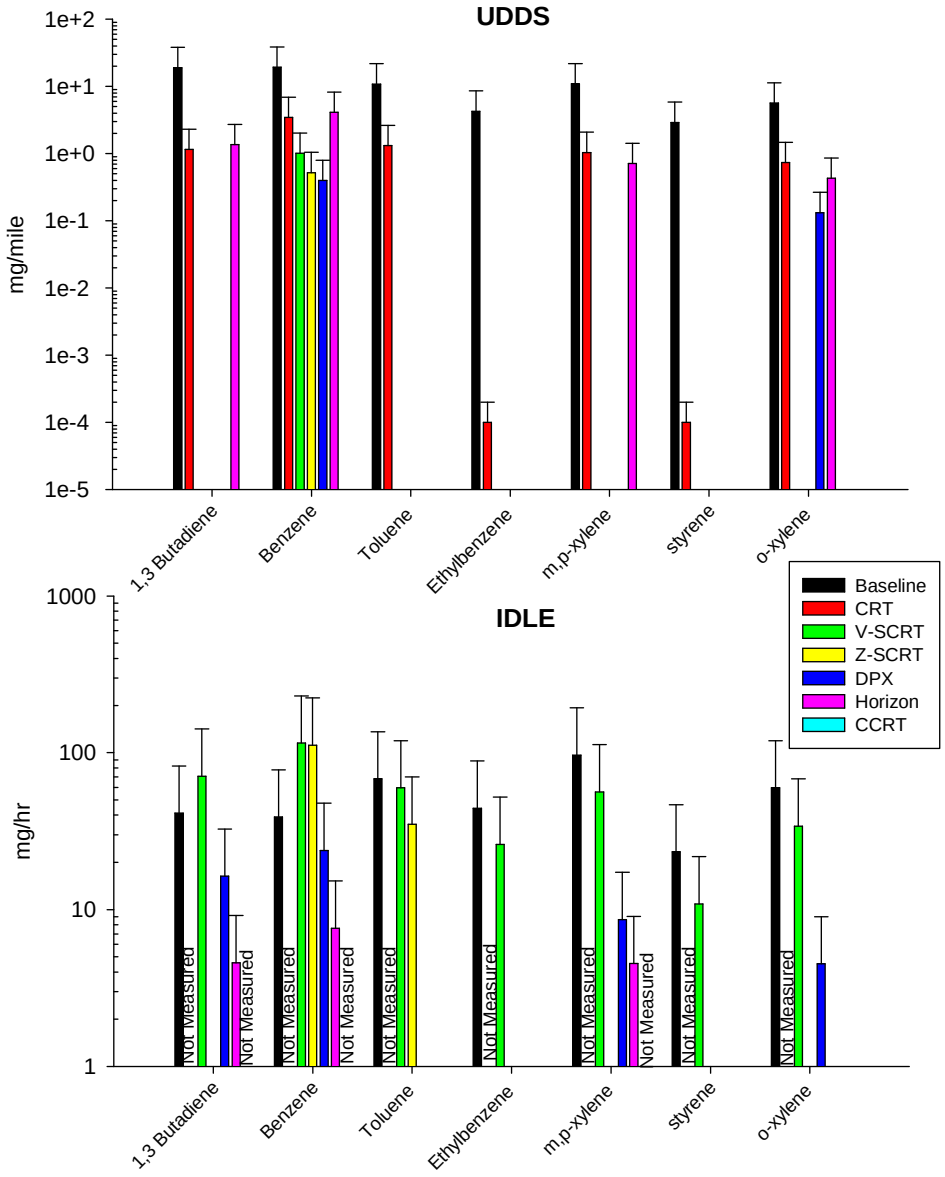
# Air Toxics (Benzene, Toluene, Ethylbenzene and Xylene )




## Cruise and UDDS Cycles

- Greater than 70% reduction of BTEX by all retrofits
- For some emissions are below background

## Idling

- Greater than 70% reduction of BTEX by most aftertreatment devices
- But, increased levels of Benzene observed from DPF+SCR retrofits

a. No measurements for CRT and CCRT during idle operation
b. Values not displayed are below the levels of filtered ambient air

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# Final Remarks

- Well-functioning retrofits are performing as designed. They reduce emissions significantly (EC/OC, PAHs, BTEX).
- No surprises. Just a few remaining questions.
- Some retrofits are prototypes. So there is room for optimization in production-ready systems
- Chemical composition of PM emissions is altered by retrofits
- Elevated sulfate and ammonium correspond to retrofits that also exhibit high particle nucleation
- Study presents significant challenges for analytical analysis due to very low mass emissions from retrofit-equipped vehicles
- Future work:
  - Complete analysis/publication of results for heavy-duty vehicles
  - Study passenger cars fueled by diesel, E85, CNG, gasoline, biodiesel

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# *THANK YOU*

# *Questions?*

More about vehicle emissions research program by CARB:

http://www.arb.ca.gov/research/veh-emissions/veh-emissions.htm

# *See Also at AAAR08:*

- 8D.5 Wednesday 4:15pm: *Novel Approaches for Speciation of Platinum and Vanadium in Mobile Source Emissions.*
- 9A.1 Thursday 9:20 am: *Chemical Speciation of PM Emissions from Heavy-Duty Diesel Vehicles Equipped with DPF and SCR Retrofits.*
- 9A.26 Thursday 9:20 am: *Elements Emitted from Advanced Technology Heavy Duty Diesel Vehicles.*
- 10A.3 Thursday 11:15am:*Toxicity of Particulate Matter from Heavy-Duty Vehicles Retrofitted with Emission Control Technologies.*